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Overview and Summary
(by Beth Kaeding, February 15, 2009)

Myers, T., in press. **Groundwater management and coal bed methane development in the Powder River Basin of Montana.** Accepted for publication, J Hydrology

Abstract

Coal bed methane (CBM) development will eventually pump more than 124 000 ha-m of groundwater, or more than 40% of the recharge, from the coal seam and sandstone aquifers of the Montana portion of the Powder River Basin (PRB). This will relieve the hydrostatic pressure, by causing a drawdown in the potentiometric [**NOTE**: the measure, comparison, or control of electric potentials] surface and drawing groundwater from storage and natural discharges, to release the methane gas. A numerical groundwater flow model simulated drawdown that will exceed 90 m in the middle of the CBM fields with 6-m drawdown extending up to 29 km from the fields. Simulation results indicate that river flux [**NOTE**: flow] will decrease up to 40% and drawdown will encompass hundreds of wells and springs. Recovery requires up to 45 years for significant decreases in river flux to recover and is not complete for 200 years. CBM development impacts can be mitigated in two ways. First, reinjecting produced water into depleted coal seams would replenish the lost storage so that recovery would draw less groundwater from long distances. Second, rapid infiltration basins near potentially-affected rivers could decrease the short-term river flow depletion. Modeled artificial recharge replaced up to 4 000 ha-m of deficit in the depleted coal seams and is a feasible option for mitigating some effects of CBM development. Reinjection would be more effective if the development period were lengthened.

- **NOTE**: Groundwater drawdown will exceed 90 meters (~ 292 feet) in the middle of CBM fields with 6 meter (~ 19 feet) drawdown extending up to 29 kilometers (~ 46 miles) from the fields.

Facts from and points made in manuscript:

Background:

- Widespread CBM development in the Montana Powder River Basin (PRB) began in 1999 at the CX Ranch well field. At full development, the Montana PRB could have almost 25,000 CBM production wells, which would potentially produce more than 1,100,000 hectare-meters (8,917,924 acre-feet) of groundwater.
- CBM development removes groundwater from valuable aquifers and causes a potentially substantial drawdown.
- The hydrologic properties of coal seams as compared with nearby sandstone aquifers make them important regional aquifers supporting many wells.
- This paper considers the observed and modeled extent that drawdown has and could extend from the CBM fields and the potential impacts on springs and streamflow that could occur due to full development of CBM in the Montana PRB.
- Recharge in the PRB occurs in three ways. The first is diffuse net recharge, the difference between infiltration and evapotranspiration, across the basin. The second is infiltration/ recharge of runoff flowing in streams and rivers. The third is a special case of the first: recharge through clinker outcrops.
- Recharge may be estimated by assuming that the baseflow represents groundwater discharge at close to steady state, a valid assumption in a regional-scale system dominated by spring runoff and baseflow.

- The PRB drains northward toward the Yellowstone River, and the lower reaches of major rivers gain flow due to groundwater discharge. Several rivers such as the Powder River, Tongue River, Hanging Woman Creek, and Rosebud Creek flow north and have eroded into and through the Fort Union formation. Baseflow in these rivers depends on groundwater discharge.
- Coal mine dewatering and CBM development causes the most substantial groundwater development in the PRB, as noted by monitoring wells maintained by the Montana Bureau of Mines and Geology (Fig. 5). Coal mine dewatering caused long-term drawdown of as much as 15 m over 20 years in well WR-54, followed by about 40 m in six years of CBM development (Fig. 6). Rapid drawdown to as much as 70 m has occurred to well WR-27 within one-half km of a CBM field (Fig. 6). Drawdown is substantial but occurs more slowly in wells more than one-half km from a CBM field (Fig. 6, WR-53). [**NOTE**: I have left this "factoid" exactly as written, but, even though it is useful, as you can see without the figures and some translation to English units, it is difficult to use the paper's findings except in general ways. By the way, this was an "easy" few actual sentences to share with you.]
- The rate that coal-seam monitoring well levels respond to CBM development depends on their distance from the CBM fields and the depth of the coal seam. Close-in wells experience rapid water level drops consistent with the drawdown cone quickly developed by the production wells. It happens quickly because maximum CBM production depends on rapidly depressurizing the seams. Coal seam wells farther from the CBM development drawdown slower as a function of the hydrologic properties between the monitoring well and CBM field.
- Changes in stage at the Tongue River Reservoir affect the water level in nearby coal seam aquifers . . . as confirmed at monitoring wells near the Tongue River and Tongue River Reservoir. For example, water levels at wells WRE-12, WRE-13, and PKS-1179, screened in Anderson/Dietz coal, vary with the reservoir, coal mining, and CBM. Beginning in 1980, mine dewatering began to dampen the seasonal changes and lower the water levels. The rate of decline increased due to nearby CBM development in early 2003.

<u>Description of Model [Note: technical description goes on for pages; this is a general overview]</u>:

- A groundwater model numerically simulating the conceptual flow model of the basin was developed to estimate the impacts of future CBM development at locations distant from the current development and to consider the effect of hypothetical reinjection scenarios. The model simulates steady state inflow as recharge throughout the basin and groundwater flow from Wyoming and outflow as discharge to springs, streams, and out-of-the-model domain to the north to the Yellowstone River. The scale is regional, and the model does not include perched aquifers or existing pumpage. Additional recharge occurs in certain areas as seepage from streams.
- In transient mode, the model includes induced and seasonal stresses as may occur in the model domain due to CBM development, a massive new stress applied to the coal seam aquifers. The stress changes continuously with time throughout the period of CBM production, assumed to be 20 years, because the pumping rate changes to maintain the potentiometric [**NOTE**: the measure, comparison, or control of electric potentials] surface about 5 m above the top of the coal seam. The model simulates the change in the potentiometric surface for the various layers due to CBM development and the subsequent changes in discharge to springs and streams. Development is simulated based on the best available estimate of sections projected to be developed.

- The model design employed the concept of parsimony [**NOTE**: the simplest, logical, and most defensible explanation for the observed data] balancing the desired precision and the sparse knowledge of the geology. Grid design balanced the need for computational efficiency around stressed cells with the lack of precise knowledge of the geologic layers. Coal bed methane pumping causes substantial drawdown over large areas within the well fields; therefore, these areas, simulated as drains were discretized to 0.8 km squares. Nine layers were used to model the stratified geology. Layer 1 is the top of the model and represents both the Fort Union and Wasatch formation outcrops. The top elevation was based on the average elevation within the cells. Layers 2, 4, 6, and 8 are coal seam layers 9.1, 7.6, 15.2, and 15.2 m thick, respectively. The Anderson/Dietz, Canyon, Carney, and Knobloch coal seams were included. There are up to ten potentially developable coal seams, therefore, the coal seam layers analyzed herein should be considered generically. Intervening layers were sandstone or other sedimentary rock with a thickness depending on the elevations of the coal seams. Coal seam elevations were based on well logs and geologic cross-sections. Layer 9 represents the underburden, which consists of various materials including deep sedimentary layers such as the Madison aquifer.
- CBM development lowers the potentiometric surface to about 4 m above the top of the coal seam at CBM wells. However, the shape of the potentiometric surface over a given area affected by a well complex is the sum of overlapping drawdown cones. To simulate water removal over a large area, the MODFLOW drain boundary routine was used to emulate a well field.

<u>Results of the Modeling</u>:

- CBM fields commence development at variable times, which causes maximum drawdown and extent to vary across the area. The maximum drawdown at some well fields may occur before other fields have commenced pumping. Drawdown expands with recovery at the fields and may overlap with drawdown from new fields just being developed.
- Maximum drawdown occurs in the deeper layers. Drawdown is higher near outcrops because the outcrops are no-flow boundaries causing there to be little water available to replenish the pumping. Seepage limits the drawdown near rivers; for example, this reflects the observed hydraulic connection along the Tongue River.
- Recovery from pumping occurs by redistributing the water stored in the aquifers and by diverting recharge from its natural point of discharge to the area of deficit. It draws groundwater from a distance that spreads the deficit across a much larger area until it is replenished by replacing discharge to other natural discharge points such as springs and streams. To return to close to pre-existing water balance conditions, the natural discharge must be decreased.
- Recovery in the middle of the fields occurs relatively quickly due to the steep gradient existing upon the cessation of pumping. Just five years after pumping ceases in the CX Ranch area or the fields between the Tongue River and Hanging Woman Creek, the drawdown has substantially recovered. Considering 6-m (~ 19 feet) contours, recovery 15 years after pumping ceases is complete except for on the east side of the domain. The continuing 12-m (~ 39 feet) drawdown occurs on a mountainous area where the initial water levels had been a groundwater divide. Drawdown also continues along the Wyoming border due to residual drawdown in Wyoming.

- Shallow aquifers recover more slowly in regions not close to a river because they are limited by low recharge so recovery requires upward flow from lower layers, which is limited by low vertical conductivity.
- About 55,500 ha-m (449,950 acre-feet) will be removed from storage by pumping in 40 years. Almost-full recovery will require more than 200 years, but residual storage depletion is not obvious on maps because drawdown of only a meter or less (~ 3 feet) occurs over a large portion of the PRB.
- Coal bed methane pumpage affects the flow to the nearby rivers with total river flux dropping by almost half at its most extreme. The flow to Hanging Woman Creek decreases from 0.17 m^3/s discharging to the river to almost 0.03 m^3/s being drawn from it [**NOTE**: 0.008 cfs and 0.0015 cfs, respectively—this is definitely an ephemeral stream]. Hanging Woman Creek may be the most affected because there will be nearby development for most of the development period.
- Coal bed methane development also affects springs and wells. The maximum extent of a drawdown cone occurs at differing times depending on the CBM development schedule and the varying recovery rates around the CBM fields. The shallow portions of the drawdown cone will continue to expand even as the nadir of the cone begins to rapidly recover. The maximum extent of the 0.3 and 6 m drawdown contours eventually encompasses 781 springs and 1 890 wells, respectively. Many of these could be affected by CBM development at some point during the development or recovery period.

<u>Myers Predictions with Reinjection Based on his Model</u>:

- The reinjection scenario saved about 4,070 ha-m (32,996 acre feet) of groundwater over the life of the development. Approximately 10% of the lost flux [flow] to rivers was saved. . . . Full recovery occurs about 10 years earlier with reinjection, although some of the reinjected water flowed south to Wyoming. The reality is that reinjection will cause the water level to recover more quickly than modeled.

<u>Myers' Conclusions</u>:

- CBM development has and will continue to deplete groundwater in the southern portion of the PRB in Montana. It will remove a large proportion of the natural recharge and decrease the groundwater discharge to rivers. Discharge to the rivers, on average, will decrease about 25%. Drawdown may affect hundreds of wells, springs, and surface water rights because CBM pumpage equaled about 36% of modeled recharge, with about 44% of the pumpage being drawn from storage. The decreased storage slowly transfers the effects to the river fluxes [flows] as natural discharges are displaced.
- The drawdown and concomitant impacts last far beyond the end of CBM pumping, but the discharge over the long term was decreased only a few percent. The long-term effects are caused by replenishing the depleted storage. Recovery will require up to 50 years, although some effects of the depletion will occur for much longer.
- CBM development impacts can be mitigated in two ways. First, reinjecting produced water into depleted coal seams would replenish the lost storage so that recovery would draw less groundwater from long distances. Second, rapid infiltration basins near potentially affected rivers could decrease the short-term river flow depletion, but they should only be used if the water quality will not degrade the river water.

- Requirements of the [model] hampered reinjection planning for the scenario considered here. A limitation is that only fields that had ceased pumping could receive production water. Another limitation is that reinjection can only occur for an entire modeled period, not commence in the middle of the simulation, which would make it possible to simulate more reinjection. A longer development and pumping scenario would provide for less overlap among development regions and increase the potential for reinjection into depleted fields. Also, it might be desirable to reinject water in upper layers while producing the lower layers, a scenario that cannot be modeled with the current drain return package.
- Reinjection and artificial recharge could mitigate some hydrologic impacts of CBM development. The storage depletion would be lessened and the rivers would not lose as much groundwater inflow. Extending the period of development would increase the opportunities for reinjection and decrease the negative impacts of CBM-induced drawdown.